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THE GOODS ALLOCATION PROBLEM IN A WAREHOUSE

M. JAKUBIAK[1]

[1] *Wrocław University of Economics*

ABSTRACT: An attempt to optimize the allocation of goods in a warehouse is the subject of this paper. The goal function of established linear programming model reflects the amount of work needed to compile ordered goods in the process of order picking. The goal function takes into consideration, respectively, measuring the distance between located goods and positions of their compilation, as well as, the time norms for the internal transportation. The described model is based on the practical example. Computer program AIMMS was used to solve the presented problem.

KEY WORDS: Optimization methods, warehouse, logistics

1 INTRODUCTION

Companies constantly seek new management concepts in order to be competitive in the dynamic business environment. In the past few years an attention was given to the logistic idea of management which is based on the complex analysis of the goods and information flow. The logistic system describes it as a route on which the products travel from the supplier to the user. A detail recognition of peculiarity of commodities movement between different elements of logistic chain allows us to plan and optimize specific stages of this flow. In the modern logistic system every goods manipulation is verified at the stage of designing. Some small movements of goods, even for short distances, which are usually made in the grounds of one building (plant, warehouse), and between an object and the transport intermediary [2], are starting to play very significant role. The optimal allocation of goods at a given space allows to fully exploit the limited capacity of the object, and reduce the number of manipulation with a given product. Logistic managers supervise the warehouse in a manner which enables them to make the most of the available space. They also want to have the compiled goods easily accessible and secure. For this reason the space designed for storing is not only treated as an area with different dimensions, but, first and foremost, as a place which provides proper conditions for goods storage through a period of time. [6, p. 1-5].

2 DESCRIPTION OF THE REASERCH PROBLEM

The analyzed problem is related to the warehouse of a company which produces refrigerators. It's a warehouse which main functions are limited to: receiving, storing, compiling, and sending goods. The scheme of the warehouse is presented in the figure 1.

Refrigerators are directly collected from the production line. In one row there can only be one type of refrigerator. Rows with fridges are grouped in special zones designed for storing. In the warehouse there are 44 rows which can contain 2112 refrigerators. The company produces 15 types of refrigerators which are packed in the same kind of packaging. This factor is significant and it facilitates the creation of optimization model as all products occupy the same amount of space in the storing area. Apart from places designed for storing, the warehouse has got three places for goods compilation, called docks. They are of the same size: 6 meters wide, 12 meters long. In the docks fridges, which are for sending, are put. In this place the truck, which drives up to the gate of the dock, is also loaded. The spots for goods compilation, production line, and places for storing goods are separated from one another by passageways which are 6 meters wide. Table 1. represents the distance between the production line, the centres of every row, and docks.

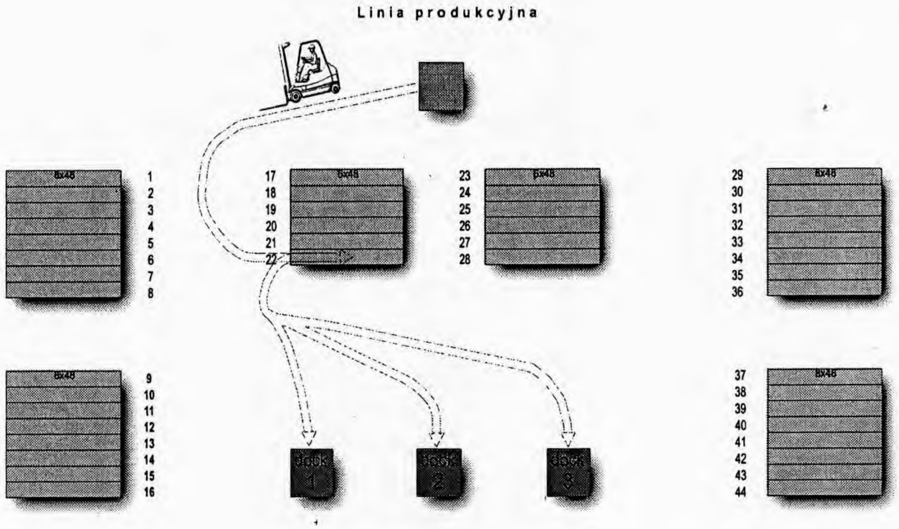

Figure 1 The outline of refrigerators warehouse and the transportation cycle
Source: Own elaboration on the basis of company's data

Table 1 Distance (in meters) between docks, the production line and rows

Row's number	The distance between dock 1 and rows	The distance between dock 2 and rows	The distance between dock 3 and rows	The distance from the production line to the docks
1	28,50	40,50	52,50	24,00
2	27,00	39,00	51,00	25,50
3	25,50	37,50	49,50	27,00
4	24,00	36,00	48,00	28,50
5	22,50	34,50	46,50	30,00
6	21,00	33,00	45,00	31,50
7	19,50	31,50	43,50	33,00
8	18,00	30,00	42,00	34,50
9	12,00	24,00	36,00	34,50
10	13,50	25,50	37,50	36,00
11	15,00	27,00	39,00	37,50
12	16,50	28,50	40,50	39,00
13	18,00	30,00	42,00	40,50
14	19,50	31,50	43,50	42,00
15	21,00	33,00	45,00	43,50
16	22,50	34,50	46,50	45,00

17	19,50	31,50	43,50	12,00
18	18,00	30,00	42,00	13,50
19	16,50	28,50	40,50	15,00
20	15,00	27,00	39,00	16,50
21	13,50	25,50	37,50	18,00
22	12,00	24,00	36,00	19,50
23	31,50	19,50	25,50	12,00
24	30,00	18,00	24,00	13,50
25	28,50	16,50	22,50	15,00
26	27,00	15,00	21,00	16,50
27	25,50	13,50	19,50	18,00
28	24,00	12,00	18,00	19,50
29	52,50	40,50	28,50	24,00
30	51,00	39,00	27,00	25,50
31	49,50	37,50	25,50	27,00
32	48,00	36,00	24,00	28,50
33	46,50	34,50	22,50	30,00
34	45,00	33,00	21,00	31,50
35	43,50	31,50	19,50	33,00
36	42,00	30,00	18,00	34,50
37	36,00	24,00	12,00	40,50
38	37,50	25,50	13,50	42,00
39	39,00	27,00	15,00	43,50
40	40,50	28,50	16,50	45,00
41	42,00	30,00	18,00	46,50
42	43,50	31,50	19,50	48,00
43	45,00	33,00	21,00	49,50
44	46,50	34,50	22,50	51,00

Source: Own elaboration on the basis of company's data

In the warehouse there is different number of rows designed for storing particular models of refrigerators (see Table 2).

In the warehouse in question the goods are stored temporarily. In other words, the number of fridges which are dispatched almost equals the number of fridges which come in from the production line.

Table 2 The number of rows designed for storing particular models of refrigerators

Model	The number of rows
1	11
2	7
3	5
4	5
5	4
6	2
7	2
8	1
9	1
10	1
11	1
12	1
13	1
14	1
15	1

Source: Own elaboration on the basis of company's data

3 THE SOLUTION OF GOODS ALLOCATION PROBLEM IN A WAREHOUSE

Goods allocation problems amount to a simple rule, according to which goods with the fastest circulation time should be allocated as close as possible to the gates of the warehouse, so as to minimize the amount of work needed for their compiling [4].

The main objective of the research is an attempt to allocate goods in a warehouse in such a way that it would be possible to minimize the working time of forklift trucks which task is to arrange and compile goods in a warehouse. In the assignment the criterion, which takes into account measured distances between located goods and the points of their compilation, and the norms of internal transportation time, was assumed.

Norms of internal transportation time are the average of various empirical calculations and the research carried out by quality controllers, and are presented as decimal fractions of a minute. Table 3. represents the time norms for a forklift truck with the load capacity of 20kN.

Table 3 Unit time norms of the basic movements of an accumulator forklift truck with a carrying capacity of 20 kN.

LP	Basic forklift truck movements	loading	unit	Symbol of the operation	Time norm (min)
1	2	3	4	5	6
1	Acceleration , empty or loaded (It appears every time when the forklift accelerates from the stop to the full speed)	empty	Full period	AE	0,0300
		loaded		AL	0,0300
2	Moving forward at a full speed (It starts, when the forklift reaches full speed after finishing the acceleration, and ends when the forklift starts to break)	empty	Per 1 metre	FE	0,0076
		loaded		FL	0,0089
3	Moving backwards at a full speed as in the example 2.	empty	Per 1 metre	RE	0,0076
		loaded		RL	0,0089
4	Stoppage (It includes breaking in order to stop	empty	Full	SE	0,0200

	the forklift from the top speed to the stoppage)	loaded	period	SL	0,0360
5	Simple entrance at the first height (includes movement of the fork lift at a very low speed, starting from the stoppage, in order to put the forks into the pallet or to position the pallet , when forks have already been lifted. The stoppage is included in the time measurement. The horizontal distance which forklift covers is 1.2 m.	empty loaded	Full period	1 NE 1 NL	0,0800 0,0800
6	Simple entrance at the second height	empty loaded	Full period	2 NE 2 NL	0,0800 0,1100
7	Simple entrance at the third height	empty loaded	Full period	3 NE 3 NL	0,1100 0,1300
8	Simple withdrawal at the first height (includes withdrawing forks from the pallet or taking out the pallet. The time is measured including moving and stopping	empty loaded	Full operation	10 E 10 L	0,0600 0,0650
9	Simple withdrawal from the second height	empty loaded	Full operation	20 E 20 L	0,0600 0,0700
10	Simple withdrawal from the third height	empty loaded	Full operation	30 E 30 L	0,0600 0,0800
11	Turning left moving forward (changing the direction of movement to the left angle 90 degrees with the minimum radius while moving forward)	empty loaded	Full operation	TFL	0,0550
12	Right turn while moving forward (change the direction of movement to the right)	empty loaded.	Full operation	TFR	0,0550
13	Left turn moving backward	empty loaded	Full operation	TRL	0,0550
14	Right turn moving backward	empty loaded	Full operation	TRR	0,0550
15	Left turn while moving forward and stoppage (this movement is usually preceded by entrance or lifting)	empty loaded	Full operation	TFLSE TFLSL	0,0600 0,0700
16	Right turn while moving forward and stoppage	empty loaded	Full operation	TFRSE TFRSL	0,0700 0,0750
17	Left turn while moving backward and stoppage	empty loaded	Full operation	TRLSE TRLSL	0,0650 0,0750
18	Right turn while moving forward and stoppage	empty loaded	Full operation	TRRSE TRRSL	0,0650 0,850
19	Tilting the mast to the back	empty loaded	Full operation	LB	0,0250
20	Tilting the mast to the front	empty loaded	Full operation	LF	0,0250
21	Lifting the forks on stoppage	empty loaded	Per 1 metre	UE UL	0,1120 0,1320
22	Lowering the forks on stoppage	empty loaded	Per 1 metre	DE DL	0,1200 0,0720

Source: [3, pp.68-69]

Setting the time for completing an order requires the company's transportation cycle to be precisely specified. The engagement (disengagement) of the load can be done by means of forklift truck, any other transportation vehicle, or even work of human. T_{01} (t_{02}) stand for the time of load engagement (disengagement), and it could be "active" for a given mean of transport (picking up the load itself), or "passive" (it is loaded). The times $t_{01,}$ t_{02} are so called fixed times of the cycle, needed for manipulation in the points of engaging and laying down the load. Apart from fixed times of transportation cycle there are times closely connected to the distance (*d*) which is covered by a given forklift from the engagement point (starting point) to the disengagement (lay down) point (target point). [3,pp. 69-70].

On the basis of transportation cycle observations in a given company, with the use of unit work time norms for a forklift truck, showed in the table 3., the time of transportation cycle has been calculated, typical of warehouse under research.

Table 4 Activities and the time of transportation cycle in refrigerators' warehouse

$t_{01/01}$ – engagement(picking up the load from the floor)	
SE	0,0266 min
LF	0,0315 min
DE 0,2 m	0,0302 min
UL 0,2 m	0,0323 min
LB	0,0315 min
10 L	0,0819 min
TRLSL	0,0952 min
AL	0,0399 min
Suma $t_{01/01}$	0,3376 min
$t_{02/01}$ – disengagement(laying down the load on the floor)	
SL	0,0478 min
LF	0,0315 min
DL 0,2m	0,0181 min
10 E	0,0756 min
UE 0,2	0,0282 min
LB	0,0315 min
TRLSE	0,0826 min
AE	0,0399 min
Suma $t_{02/01}$	0,3552 min
Activities performed when the forklift covers the distance from the engagement point (starting) to the disengagement point(target)	
TFL	0,055 min
TFR	0,055 min
FL	0,0113 min
FE	0,0096 min

Source: Own elaboration on the basis of company's data

The work of a forklift truck in transportation cycle, in the examined company, is shown at the diagram 1. The forklift picks up the fridge from the production line and transports it to the one of 44 rows in which it is stored. Next, the fridge, by means of forklift truck is transported to the one of three compilation points (docks). Forklift trucks working time on compiling goods directly depends on the distance of a given good from the dock and the production line.

In this task, the following symbols were employed:

n - the number of refrigerators allocated in the warehouse
m - the number of rows designed for storing refrigerators
R – the number of compilation points

m_j – the number of rows designed for the "j" model of fridge
d_k - the distance from the production line to the row k
d_{rk} - the distance between the compilation point r, and the row k
p_j - the average number of transportation cycles needed for compiling the "j" model of fridge
The time (t_k) of the whole transportation cycle in the examined company amounts to:

$$t_k = t_{01/01} + TFL + d_k \cdot (FL + FE) + TFR + t_{02/01} + t_{01/01} + TFL + (\sum_{r=1}^{R} (d_{rk} / R) \cdot (FL + FE)) + TFR + t_{02/01}$$

In the table 5. there are values of the average fridges' circulation calculated in the three months period reckoned up on one working day of the warehouse. By the average fridges' circulation I mean the average amount of produced and sold commodity. A forklift truck during one transportation cycle always picks up two refrigerators, that is why in the table 5. apart from the average value of circulation there is a column concerning the average number of forklift's departures for commodity. It's the value of average circulation divided into two.

Table 5 The average number of refrigerators moped in the warehouse during one day

Model of the fridge	The number of fridges	The number of forklift's departures
1	120,00	60,00
2	86,40	43,20
3	72,00	36,00
4	43,20	21,60
5	38,40	19,20
6	33,60	16,80
7	14,40	7,20
8	14,40	7,20
9	14,40	7,20
10	9,60	4,80
11	9,60	4,80
12	9,60	4,80
13	4,80	2,40
14	4,80	2,40
15	4,80	2,40

Source: Own elaboration on the basis of the company's data

The criterion of the goal function, which parameters c_{jk} stand for the average time needed to compile the commodity j from the storage point k in time t, is created according to the formula:

$$c_{jk} = t_k \cdot p_j$$

The goal function is signified as Z and it has got the following form:

$$Z = \sum_{j=1}^{n} \sum_{k=1}^{m} c_{jk} \cdot x_{jk} \rightarrow \min$$

The variable of our optimization model is signified as x_{jk} where $j = 1,\ldots, n$, $k = 1,\ldots, m$, and it has got the form of binary variable which assumes the value 1 when the row designed for storing k is occupied by the commodity j, whereas value 0 in the other case. Our model's limitations are the number of rows designed for storing particular products:

$$\sum_{j=1}^{n} x_{jk} \leq 1$$

where $j = 1,\ldots, n$,

and, the fact that one particular model of refrigerator is ascribed to one row

$$\sum_{k=1}^{m} x_{jk} = m_j$$

where $k = 1,\ldots, m$

Following the formulas shown above we come up with a model which we solve by means of AIMMS or LP SOLVE programs. The solution for this problem is shown in the table 6. One model of fridge is permanently ascribed to every row.

Table 6 Allocation of refrigerators in the rows

Model of fridge	Row's number
1	18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28
2	8, 9, 10, 11, 17, 37, 38
3	7, 12, 35, 36, 39
4	5, 6, 12, 34, 40
5	4, 14, 32, 33
6	2, 15
7	30, 31
8	3
9	41
10	29
11	1
12	42
13	44
14	43
15	16

Source: own elaboration.

The goal function has reached the value Z= 2003,00 of minutes.

4 CONCLUSION

New locations which were set in the research help to take advantage of the work of forklift trucks, which compile goods in the warehouse, more effectively. Three day empirical research carried out in the company right after the implementation of solution came up with the unsatisfying result. The average time of one commodity compilation was reduced by about 16 seconds. This value is 3 minutes slower than it was assumed, and it mainly results from the fact that the solution put into practice is new and not all workers have managed to master it. The implemented solution facilitates and helps to systematize the work in the warehouse, however its better results could be observed in a few months when the majority of workers learn the new locations of refrigerators, and take advantage of them.

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